Open Smart Energy Eco-System for the Future

Citation for the original published paper (version of record):

Haghgoo, M., Dognini, A., Storek, T. et al (2020). Open Smart Energy Eco-System for the Future.
IOP Conference Series: Earth and Environmental Science, 588(2).
http://dx.doi.org/10.1088/1755-1315/588/2/022048

(article starts on next page)

Open Smart Energy Eco-System for the Future

IOP Conf. Series: Earth and Environmental Science **588** (2020) 022048 doi:10.1088/1755-1315/588/2/022048

Open Smart Energy Eco-System for the Future

Maliheh Haghgoo[1], Alberto Dognini[1], Thomas Storek[2]
Radu Plamanescu[3], Ulrike Rahe[4], Stefan Gheorghe[5]
Mihaela Albu[3], Antonello Monti[1] and Müller Dirk[2]

[1]RWTH Aachen University, E.ON Energy Research Center, Institute for Automation of Complex Power Systems, Aachen, Germany
[2]RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Building and Indoor, Aachen, Germany
[3]Politehnica University of Bucharest, Department of Electrical Engineering, Bucharest, Romania
[4]Chalmers University, Department of Architecture and Civil Engineering, Göteborg, Sweden
[5]Energobit, Cluj-Napoca, Romania

E-mail: `mhaghgoo@eonerc.rwth-aachen.de`

Abstract. Due to the increasing complexity of the global energy system and the amount of data transmitted by smart devices, there is an urgent need to unlock smart technologies and services with investments on the scalability of computational resources. This objective can be achieved by means of a standardized software platform that can support interoperability and behave as the main vehicle for the rapid implementation of innovative energy services. One possibility to enhance computational power on demand is cloud computing, which forms the Internet of Things (IoT). In this work, a customizable open-source IoT platform setup using the FIWARE framework is deployed, which exploits the advantages for a smart energy domain. The term platform comprehends a set of software tools that allow quick integration of various devices. This study presents the implemented platform and analyses its functionality in different use cases on the European level.

1. Introduction

The United Nations' Sustainable Development Goals (SDGs) have established a continuously sharpened framework of orientation for governments and organisations to commonly strive for global and local sustainability action. In our increasingly urbanized world, more than 60% of our global population is expected to live in cities by 2030. Cities will not only be the economic driver but also contribute to about 70% of global CO2 emissions and over 60% of global resource use[1]. SDG 11 has been addressed, striving for sustainable cities and communities is therefore an obvious action area for the underlying research project presented in this paper, which develops a way forwards towards smart and more sustainable solutions for accessible energy for all, including responsibilities of diverse stakeholders. Widespread challenge as described above also demands broader efforts across several interconnected SDGs, in particular in the built environment. According to recent studies on the future of energy and energy-related emissions[2], the building sector will remain the first energy consumer by 2030. SDG 9 means to develop

[1] https://www.un.org/sustainabledevelopment
[2] https://www.iea.org/reports/world-energy-outlook-2019

quality, reliable, sustainable and resilient infrastructure to support economic development and human well-being, with a focus on affordable access to achieve environmental objectives, such as increased efficiency of resources and energy.

Nowadays, modernization of the electricity grids to increase the flexibility of the power system, the efficiency of transfer capacity and active participation of end-user are the implementation road-map in many strategic kinds of research. In this context, a standardized and open-source software platform is the key enabler of interoperability and the main vehicle for the rapid implementation of innovative energy services. To accomplish this goal a cloud-based environment is proposed, providing high scalability, fast provisioning, resilience and cost efficiency while facilitating the deployment of applications and services for utilities. Furthermore, to ease and improve the development of distributed architecture, cloud vendors are offering distributed system services, called middleware which have standard application programming interfaces (API) and protocols. Several studies focus on middleware, in the frame of project or research, as studied, compared and classified in [1, 2]. Recently, middleware development is an important concept in the design of a Service-Oriented Architecture (SOA). In SOA application components provide services to other components via communication protocol and with a standard such as Simple Object Access Protocol (SOAP) and Relational State Transfer (RESTful)[3, 4]. This architecture enables application software development through discrete units of functionality, which are self-contained interoperable and technology-neutral. FIWARE[3] is an example of this kind of architecture platform.

FIWARE is an open project sponsored by Future Internet Public-Private Partnership (FI-PPP) program, created by the European Commission to accelerate the development of smart platforms. The new use cases have been defined within the European project FISMEP (FIWARE in Smart Energy Platform)[4] to unlock a smart energy platform that facilitates the development of applications and services for utilities. The goal of FISMEP is to implement a distributed platform architecture and enlarge the partnership at the transnational level, in order to achieve the joint development of integrated solutions for smart power systems, with a relevant impact on sustainable communities.

2. Platform Overview

The main contribution of FISMEP is the creation of a completely new distributed architecture that facilitates the implementation of the new energy services and scales up the system horizontally. Building this platform on the knowledge created by FI-PPP, FISMEP takes the process a step further by developing a new set of standard interfaces for energy services. The goal is achieved by means of a multi-layered architecture, as shown in Figure 1. Layer 1 is the interface to the field. FISMEP is enriched with a set of standards protocols and data management capabilities for mapping the raw data coming from a variety of sensors and standardized data representation in the cloud [5]. Layer 2 is given by the combination of Generic Enablers (GEs), as provided by FIWARE, a set of Domain-Specific Enablers (DSEs), created in the context of FISMEP. These enablers are standard software services that can be used in different contexts. Layer 3 is the open API, which has already been developed in FIWARE and offers easy data access to third parties that need to collaborate with the utility running in the platform.

Such architecture is fundamentally new for the energy sector and potentially strong in supporting scalability on-demand. Another important aspect is the focus on the interface between energy systems, energy grids and end-users, giving the latter an active role through a new version of home energy management. In fact, the proposed architecture enables the users to, amongst others, set and manage personal energy thresholds, schedule energy-consuming

[3] https://www.fiware.org/about-us/
[4] https://fismep.de/

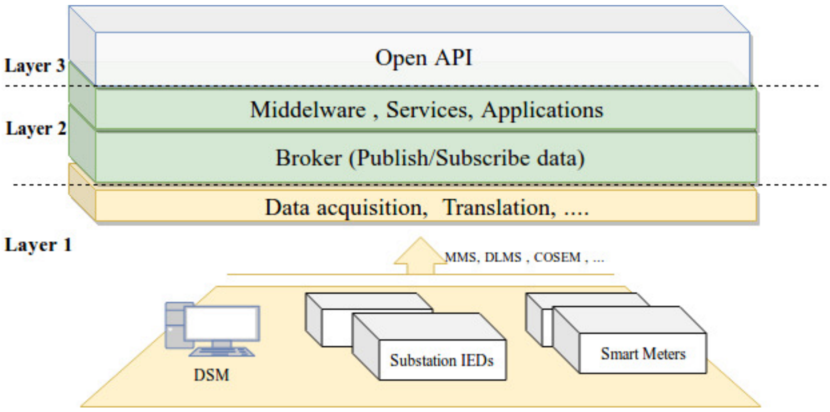

Figure 1. Three main layers in cloud-based platform

appliances and assets as well as plan energy use according to energy forecast and personal goals to achieve more sustainable behaviour patterns.

To unlock solutions on a very wide scale, a dynamic and open-source eco-system based on FIWARE solution is taken. The effort proposed in FISMEP, which is powered by FIWARE, is perfectly aligned with the unlocking strategy.

2.1. FISMEP: FIWARE for Smart Energy Platform

In the smart energy context, the FIWARE framework is used as a central system to manage and store the data. This framework contains a list of open-source services called GEs to facilitate and accelerate the development of smart internet-related application in different domains[5]. FIWARE framework is based on SOA and supports a sophisticated set of REST API using Next Generation Service Interface (NGSI) format, which is currently a de-facto standard released by Open Mobile Alliance (OMA)[6]. Several studies have been conducted in the area of smart cities [6, 7, 8] in which NGSI is used as a formal standard for context information management system. Therefore it is a promising interface for the future smart energy system. This work only uses some core GEs of the overall framework in order to prove the feasibility of FIWARE for smart energy applications and leaving the other existing GEs aside.

The Context Broker (CB) Orion is a core GE in FIWARE catalogue. It mainly eases the development and provisioning of applications that require management, processing and exploitation of context information as well as a data stream, in real-time and at massive scale or distributed format. The data itself stored in an underlying MongoDB database that belongs to CB Orion. As current data are stored in CB Orion and do not provide time related and historical information for some advance application, CrateDB and QuantumLeap are used. In the same way as CB Orion, all other GEs from FIWARE catalogue provide API for managing the historical data stored in the database. FIWARE offers IoT Agents GE to establish communication between IoT devices to the cloud platform based on predefined standard protocols.

The proposed architecture for FISMEP is a form of geographically distributed platform to consider scalability in design. This property is considered by using the new generation of NGSI called NGSI-LD [7] which has been conducted under the ETSI ISG CIM. NGSI-LD is an evolution of the NGSI v2 information model, which has been modified to improve support for linked data (entity relationships), property graphs and semantics (exploiting the capabilities offered by

[5] https://www.fiware.org/about-us/
[6] https://www.openmobilealliance.org/release/NGSI
[7] https://www.etsi.org/deliver/etsigs/CIM

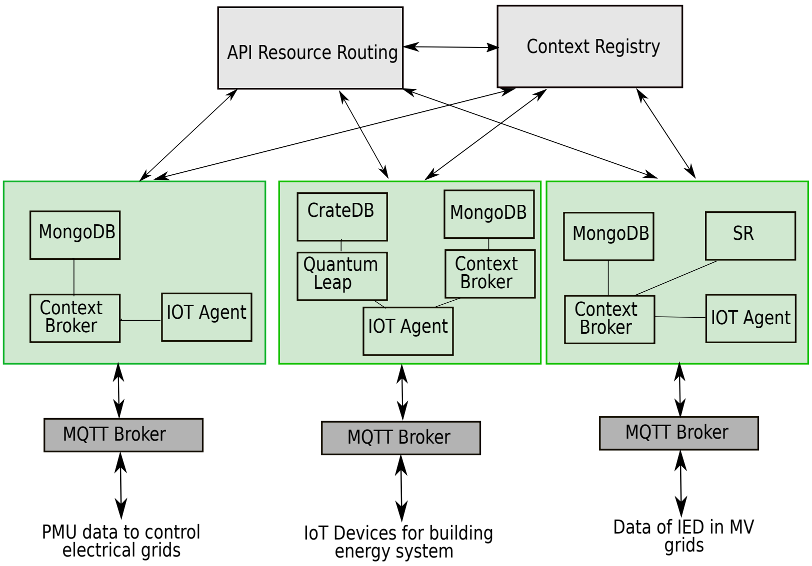

Figure 2. FISMEP platform overview

JSON-LD). Adding the new concept of Linked-Data (LD) helps to provide context information semantically and cross-cut domain-specific information. This aspect enables efficient support for designing different architecture.

Figure 2 shows a distributed architecture developed in FISMEP project. The underlying idea here is that all information is stored by the domain-specific CB. CB implements the query and subscription part of the NGSI-LD API. Each domain registers themselves with the Context Registry (CR), providing information about what context information they can provide, but not the context information itself. In this concept, context consumers (CC) can query or subscribe to the domain-specific CB. On each request, the CB discovers those that may provide context information relevant to the respective request from the CC. The Distribution CB, then, queries or subscribes to each relevant Context Source and, if possible, aggregates the context information retrieved from the Context Sources, providing them to the CC. In this mode of operation, it is not visible to the CC, whether the broker is a central broker or a distribution broker.

3. Use Cases

This section presents the implementation of the platform in different use cases in three European countries Sweden, Romania, Germany. In the Swedish use case (UC1), a sustainable living environment, energy management services are applied to real residential buildings down to the end-user level, including their energy behaviour. The German use case (UC2) deploys the implementation of automated service restoration for distribution grids in medium voltage level. The Romanian use case (UC3) realizes monitoring of distribution grid at different voltage levels using data from Phasor Measurement Units (PMUs). In the following, the detail of use cases is presented.

3.1. UC1 : Building Energy Management Systems and User Involvement

Today, two-thirds of the building energy consumption is used for heating ventilation, air conditioning and refrigeration (HVACR) [9, 10, 11]. Optimizing the operation of building energy systems (BES) holds great potential for energy savings [12, 13]. However, due to the integration of volatile, decentralized energy sources and the coupling of the thermal and the electrical domain significantly increases the complexity of future BES. Applying classical control strategies may reach their limits and become too cumbersome to implement and to maintain. Applying advanced control algorithms may overcome these issues, whereas energy savings of about 20 % to 35 % and reduction in operation cost of up to 73 % are already reported [9, 10, 11]. However, practical implementations of these algorithms are still quite rare. Not only do they require a lot of expert knowledge but also the integration into the existing building automation system (BAS) infrastructure is an ongoing issue. The integration of the BAS into a standardized cloud platform will not only solve the communications issues but also offers the use of interpreted programming languages but also on provides on-demand hardware capacity that might be occasionally needed by the algorithms [14].

As ICT is increasingly introduced to energy networks as well as housing and household appliances, new opportunities are created for the supply of energy, its consumption and the interaction with the energy system. A key pillar of the Swedish use case is, therefore, a user-centric approach, with the goal to study the potential of conscious and committed end-users of energy in the future energy system, assumed that they can actively contribute to reducing power peaks and environmental impact through their behavioural choices. With HSB Living Lab (HLL), the research team has had a ready-to-make-use-of "3rd generation Living Lab" on Chalmers campus at their disposal - a residential building and a unique 'real-world' user-centred test lab for prototyping and innovation piloting for the research and development of sustainable technology and behavioural practices in and connected to smart energy consumption. Being at the same time a home to approximately 33 students and researchers, it offers a unique co-creation platform for experimentation, allowing collaboration and fostering innovation between academic research, industry and the end-users. In this regard, the HSB Living Lab offered a perfect playground to the first-hand testing of ERO, a smart application developed by the Swedish team, to facilitate the active participation of end-users. In contrast to commercially available smart home energy systems, ERO facilitates demand shifting by letting the end-user act according to a self-defined energy threshold and thus assume a more active role in the energy system. In an energy network combining district energy and electricity, the end-user can also choose the type of energy that is most appropriate at the time given. Instead of just encouraging end-users to reduce their energy use, ERO gives tips on when it might be smart to use, for example, household appliances or hot water, based on which energy mix is preferred or forecasts from the energy networks, users can shower when there is a large production of a desired type of energy in the networks. In addition, the energy suppliers receive valuable forecasts of consumption data through the app. In the HSB Living Lab study, see even [15] a majority of the participants reported relating their energy use to the status of the energy system, due to ERO. The possibility to set an own personal energy threshold was very appreciated by most of the participants. As the participants only were able to control a limited number of appliances of relatively low energy consumption, only a few made ERO an integrated part of their daily life. A tentative result from the ERO testing [15] is that it has the potential to facilitate shifting energy demand and would be relevant for homes controlling bigger loads, such as electric vehicles or washing machines. In the proceedings of the FISMEP project, this will be further investigated by the Swedish team, both on a larger scale in a "normal" residential building and outside of the living lab context.

3.2. UC2: Automated service restoration for distribution grids
The occurrence of outages in electrical networks causes several economic and social impacts. Currently, most of the utilities are not fully automated and the operations related to fault management are manually implemented by human technicians [16]; anyway, the consequences of faults can be reduced by equipping the grids with automation solutions. This reinforcement strategy increases the reliability of the distribution systems, minimizing the interruption of power delivery (in particular to critical infrastructures as hospitals, gas network pumps or cellular base

stations) and restoring the normal operation condition in the minimum time [17]. The modern automated grids deploy advanced self-healing capabilities by applying Fault Location, Isolation and Service Restoration (FLISR) key blocks. The goal of FLISR is, firstly, to accurately locate the fault position in the network, in order to open the nearest circuit breakers and interrupt the fault conditions; secondly, the grid is re-configured to re-energized the disconnected loads. The implementation of FLISR functionalities in the Distribution Management Systems (DMS) of electrical grids requires the continuous analysis of a large amount of data from the field devices and a high level of performance for the execution of the algorithms. Once an electrical fault occurs in the network, the protection system has to promptly act in order to limit the risks for people and the damages of installed components. This action consists of identifying the faulty section of the grid and opening the nearest switching devices, upstream and downstream, in order to clear the abnormal condition and isolate the fault zone. The goal of the Service Restoration (SR) is to re-energize the customers that are disconnected after the fault clearance but are outside the fault zone. These customers can be reconnected by performing the power delivery with an alternative path and closing the normally open tie switches, which connect two different feeders and are installed in the distribution grids to increase its resiliency. To enhance the self-healing capability of distribution grids in case of fault occurrence, a SR solution has been developed and implemented in the FISMEP platform. The SR is based on an innovative Rule-Based Optimization (RBO) algorithm, specifically developed as the first countermeasure in critical conditions, as High Impact Low Probability (HILP) events[8]. The RBO algorithm is activated once the circuit breakers clear the fault area; among the de-energized loads that can be reconnected, the one having the highest priority (i.e. the most critical one) is chosen as a target for the service restoration. Each alternative network topology, obtained by closing a normally open tie switch to allow the energy supply to the target load from one of the primary substations, is evaluated. The topology guaranteeing the minimum total power losses is implemented, verifying also the respect of constraints about radiality of the network, voltage and thermal limits. The SR has been developed as middleware, hence it is independent of grid structure or specific electrical parameters. Moreover, it is integrated into the FISMEP platform with the FIWARE components, to deploy an automated cloud-based SR. To test the SR, the distribution grid is emulated in the Real-Time Digital Simulator (RTDS) with the software RSCAD. Through the Gigabit Transceiver Network (GTNET) card of RTDS the grid data could be sent/published into a communication network via its ethernet port thus emulating the protection and metering devices. The test is carried out on different grids and fault conditions; additionally, the recorded communication network latency and the SR computation time are in line with standard values of automated systems, confirming the suitability of the proposed setup.

3.3. UC3: High time resolution grid monitoring using PMUs
Presently, energy systems face several challenges, all related to the increased complexity of the components (generators, loads and storage with interchangeable functionality) but also to a paradigm change related to the way energy flows are managed dynamically and within evolving constraints (lower carbon footprint, increased mobility, etc.). One solution at the edge of ensuring continuous operation on both old and new "energy entities" is to intelligently process available information and this is linked to new measurement systems with features like high reporting rate and synchronized data. PMUs are the first generation of such ubiquitous measurement systems dedicated to power system wide-area measurement an control.PMU streams data from locally estimated quantities (voltage, frequency, current, power), using short measurement windows (40-670 ms) and reporting the information every 10 ms, if necessary. This results in a high

[8] https://www.fein-aachen.org/en/projects/rbosr/

volume of data [18, 19].

The using of the functions of PMUs in the measurements in Power System (PS) gives the possibility to access the information about the state of the system not only in the normal operation but also in the critical state. PMU technology allows increasing the accuracy of the measurements, together with a better estimation of causes and evolution of any incidents, including arc faults in the supervised area. In this study, the PMUs are installed in few nodes of HV grid monitoring and are connected by current and voltage instrument transformers from the substations of Power Grid. Each PMU is identified by an ID and its position is taken from GPS coordinates. There are 5 PMUs integrated into the FISMEP platform and connected to the power grid as follows: the first PMU on the 110kV bus bar of a DSO substation, monitoring the energy transfer on an overhead line; the second PMU in a DSO substation, on 20 kV busbar, monitoring the parameters of a cable feeding an industrial customer; the third PMU on the LV side of the power transformer connected to a local industrial customer. The fourth PMU at LV main supply of the MicroDERLab platform in UPB; In addition, the last PMU is used for testing purposes and connected to the LV laboratory network of EnergoBit. According to the aforementioned details of PMUs, FISMEP platform monitors the voltage in the LV nodes for checking compliance with power quality standards and norms, on lower time intervals than those in use and for further testing potential correlation with variable loads in weak grids. Additionally, frequency is monitored on the HV side of distribution networks, for estimating the source and impact of abnormal states in the supervised network, following either local events or propagated from incidents in the transmission network.

4. Suitability of FISMEP for Smart Energy System

The suitability of the platform in the smart energy system is analyzed in terms of "energy as a service". The availability of software building blocks, which allow the fast development of new applications, lets the users focus on the energy concepts as their main business, instead of ICT issues; another important aspect is represented by the availability of basic services that support the prototyping of new applications in smart energy domain.

Unified view of the data: by using common API, context consumers can access data of various devices according to the use cases. Additionally, distributed architecture as proposed in this project makes possible to get direct access to data from any other use case; hence, the cross-data flow of use cases is also covered.

Availability of software building blocks: some of the implementation-independent functional building blocks are already defined by open specifications and an open-source reference implementation in FIWARE GEs and FINESCE DSEs. FISMEP Platform has demonstrated how groups of these building blocks can be combined together. Moreover, the system latency of building blocks is evaluated in the aforementioned use cases. To consider the availability aspect, all necessary services must be available as open-source software building blocks, which can be used by any developers to implement their own systems.

Availability of basic services: it refers to the domain-specific services in the FISMEP platform. Some services are defined and implemented within the project according to the new list of requirements in the use cases. They are available for external usage or further development in the energy domain. The result of the use cases proved the feasibility of the easy integration of services into the platform.

5. Conclusion

As evinced by the results, the proposed architecture contributes to improving the energy system by offering re-usable and open-source services without any national boundaries, besides the achievement of scalability via cloud-based solutions. From the successful demonstrations, the presented platform is suitable as a customizable, cost-inexpensive but yet powerful solution for future smart energy eco-system powered by FIWARE. A key challenge in the smart energy system is the diversity of the requirements of the use cases in terms of communication latency, data rates and applications on demand. FISMEP platform addresses these aspects by implementing an open and distributed architecture that allows the integration of building blocks for specific use cases and scales up according to the number of domain information. As presented, the suitability of the platform has been tested in the three demo sites of different European countries.

5.1. Acknowledgments
This work is part of the project "FISMEP - FIWARE for Smart Energy Platform", sponsored by the German Ministry for Industry and Energy (project number 0350018A), the Swedish Energy Agency (project number 42804-1), the Romanian Executive Agency for Higher Education, Research, Development and Innovation (Funding number UEFISCDI and Contract numbers 79/2017, 80/2017) under the head of the ERA-Net Smart Energy Systems programme.

References

[1] Mineraud J, Mazhelis O, Su X and Tarkoma S 2016 A gap analysis of internet-of-things platforms vol 89 (Elsevier) pp 5–16
[2] Balamuralidhara P, Misra P and Pal A 2013 Software platforms for internet of things and m2m vol 93 pp 487–498
[3] Zhou H 2012 *The internet of things in the cloud: A middleware perspective* (CRC press)
[4] Guinard D, Trifa V, Karnouskos S, Spiess P and Savio D 2010 Interacting with the soa-based internet of things: Discovery, query, selection, and on-demand provisioning of web services vol 3 (IEEE) pp 223–235
[5] McKeever P and Monti A 2016 Bottom-up approach to energy services platform *2016 IEEE International Energy Conference (ENERGYCON)* (IEEE) pp 1–6
[6] Namiot D and Sneps-Sneppe M 2016 On the domestic standards for smart cities vol 4 pp 32–37
[7] Latre S, Leroux P, Coenen T, Braem B, Ballon P and Demeester P 2016 City of things: An integrated and multi-technology testbed for iot smart city experiments *2016 IEEE International Smart Cities Conference (ISC2)* (IEEE) pp 1–8
[8] Sotiriadis S, Stravoskoufos K and Petrakis E G 2017 Future internet systems design and implementation: cloud and iot services based on iot-a and fiware *Designing, Developing, and Facilitating Smart Cities* (Springer) pp 193–207
[9] Afram A and Janabi-Sharifi F 2014 Theory and applications of hvac control systems – a review of model predictive control (mpc) vol 72 pp 343–355
[10] Baldi S, Michailidis I, Ravanis C and Kosmatopoulos E 2015 Model-based and model-free "plug-and-play" building energy efficient control vol 154 pp 829–841
[11] Killian M and Kozek M 2018 Implementation of cooperative fuzzy model predictive control for an energy-efficient office building vol 158 pp 1404–1416
[12] Fütterer J P, Schild T P and Müller D 2017 Gebäudeautomationssysteme in der praxis "http://publications.rwth-aachen.de/record/691150
[13] MeGA 2016 Marktstudie 2016 gebääudeautomation schweiz www.mega-planer.ch
[14] Storek T, Lohmöller J, Kümpel A, Baranski M and Müller D 2019 Application of the open-source cloud platform fiware for future building energy management systems *Journal of Physics: Conference Series* vol 1343 (IOP Publishing) p 012063
[15] Renström S, Andersson S, Jonasson A, Rahe U, Merl K and Sundgren M 2019 Limit my energy use!an in-situ exploration of a smart home system featuring an adaptive energy threshold *The 19th European Roundtable on Sustainable Consumption and Production – Circular Europe for Sustainability* (Proceedings of ERSCP)
[16] Zidan A and El-Saadany E F 2012 A cooperative multiagent framework for self-healing mechanisms in distribution systems vol 3 pp 1525–1539
[17] Panteli M and Mancarella P 2015 The grid: Stronger bigger smarter?: Presenting a conceptual framework of power system resilience vol 13 pp 58–66
[18] Plamanescu R, Albu M, Gheorghe S, Bugnar S and Coroiu M 2019 Pmu cloud-based applications for power systems insight *2019 54th International Universities Power Engineering Conference (UPEC)* pp 1–5
[19] Plamanescu R, Gheorghe S, Sarb M, Istenes A and Albu M 2019 A synchronized measurements fiware platform for smart grid applications *2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE)* (IEEE) pp 1–5